MEASUREMENT OF MULTIPLICITY FLUCTUATIONS IN PROTON PROTON COLLISIONS

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ABSTRACT

Using the ROOT software, we aim to analyze **fluctuations of charged particle multiplicities** in proton-proton collisions which have been measured using the ALICE detector at the CERN Large Hadron Collider (LHC) in the pseudorapidity range $|\eta| < 1.0$ and transverse momentum $p_T > 0.05GeV/c$. To quantify the magnitude of these fluctuations, we use the **scaled variance**, i.e. the variance normalized by the mean of the multiplicity distribution. Our objective is to study the evolution of these fluctuations with respect to collision centrality.

I. INTRODUCTION

The dataset provided has been generated using the **Pythia 8 Monte Carlo Event Generator**.
Number of events : **2 million**
Collision System : **proton - proton** with impact parameter $\sqrt{s_{NN}} = 2.76TeV$
We begin with defining a few important variables:

- **Multiplicity**: The number of new particles generated in a particular proton-proton collision. The multiplicity constitutes an important observable, which reflects the properties of the hot and dense system formed in the overlap region between the two incoming nuclei. Even without more detailed and differentiated measurements of the emitted particles, one can obtain important information about the collision from measurements of the total multiplicity of charged particles, its distribution in pseudorapidity space (angular dependence) and its dependence on collision centrality and energy.
- **Pseudorapidity**: In experimental physics, it is the spatial coordinate describing the angle of a particle relative to the beam axis. It is defined as:

$$\eta = -\ln \tan(\theta/2),$$

  where θ is the angle between the particle three-momentum $\mathbf{p}$ and the positive direction of the beam axis. Pseudorapidity is particularly useful in hadron colliders such as the LHC, where the composite nature of the colliding particles means that interactions rarely have their centre of mass frame coincident with the detector rest frame, and where the complexity of the physics means that η is far quicker and easier to estimate.
- **Transverse momentum** : The component of momentum transverse (i.e. perpendicular) to the beam line. It's importance arises because momentum along the beam line may just be left over from the beam particles, while the transverse momentum is always associated with whatever physics happen at the vertex.
- **Scaled variance**: It is the variance of the multiplicity distribution divided by its mean. It is a useful and standard statistic for quantifying multiplicity fluctuation.

$$\omega_{ch} = \frac{\sigma_{ch}^2}{< N_{ch} >}$$

  where σ_{ch} and $< N_{ch} >$ are the standard deviation and mean of the multiplicity distribution, respectively.

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II. RESULTS AND DISCUSSION

In this section, histograms of the multiplicity distribution of charged particles v/s number of particles for proton-proton collisions corresponding to each multiplicity class, namely **pytree020**, **pytree2040**, **pytree4060**, **pytree6080**, **pytree80100** and **pytree100**, have been plotted.

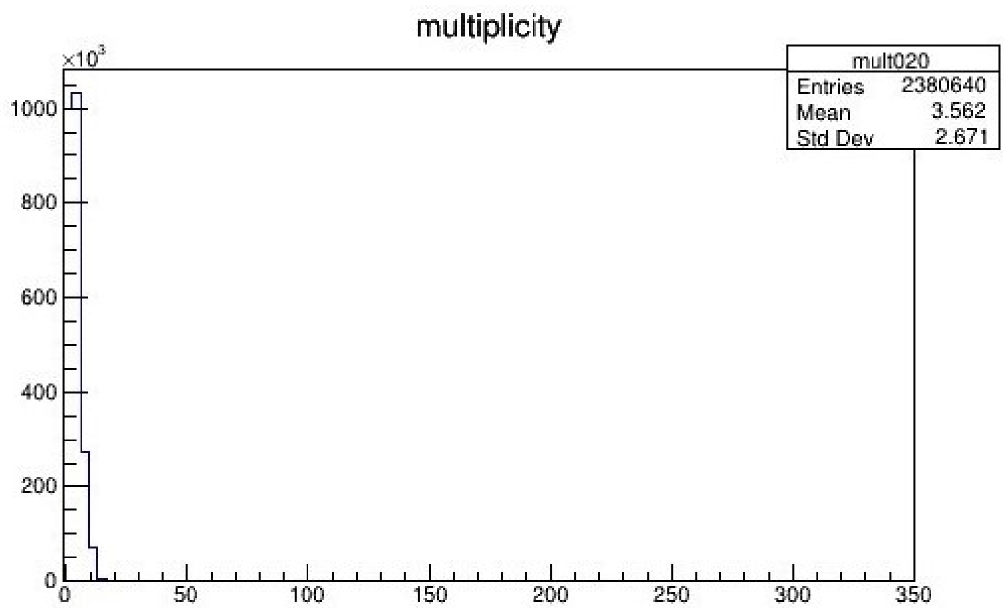

Figure 1. Distribution of multiplicity for proton-proton collisions in the multiplicity class pytree020
$\langle N_{ch}\rangle = 3.562 \quad \sigma^2_{ch} = 7.134 \quad \omega_{ch} = 2.003 \quad \sigma^2_{ch}/\langle N_{ch}\rangle^2 = 0.562$

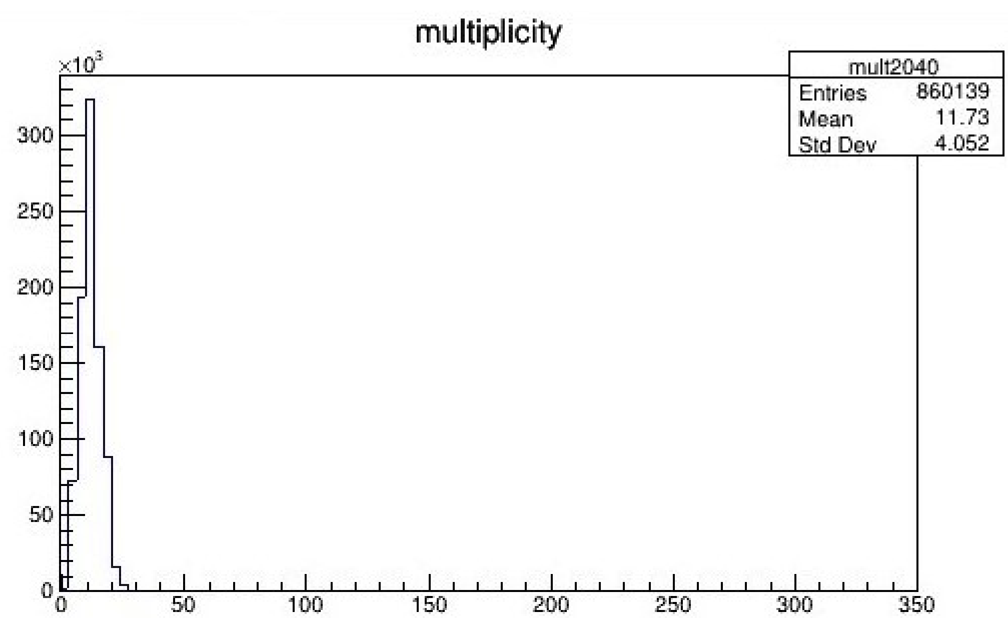

Figure 2. Distribution of multiplicity for proton-proton collisions in the multiplicity class pytree2040
$\langle N_{ch}\rangle = 11.73 \quad \sigma^2_{ch} = 16.419 \quad \omega_{ch} = 1.400 \quad \sigma^2_{ch}/\langle N_{ch}\rangle^2 = 0.119$

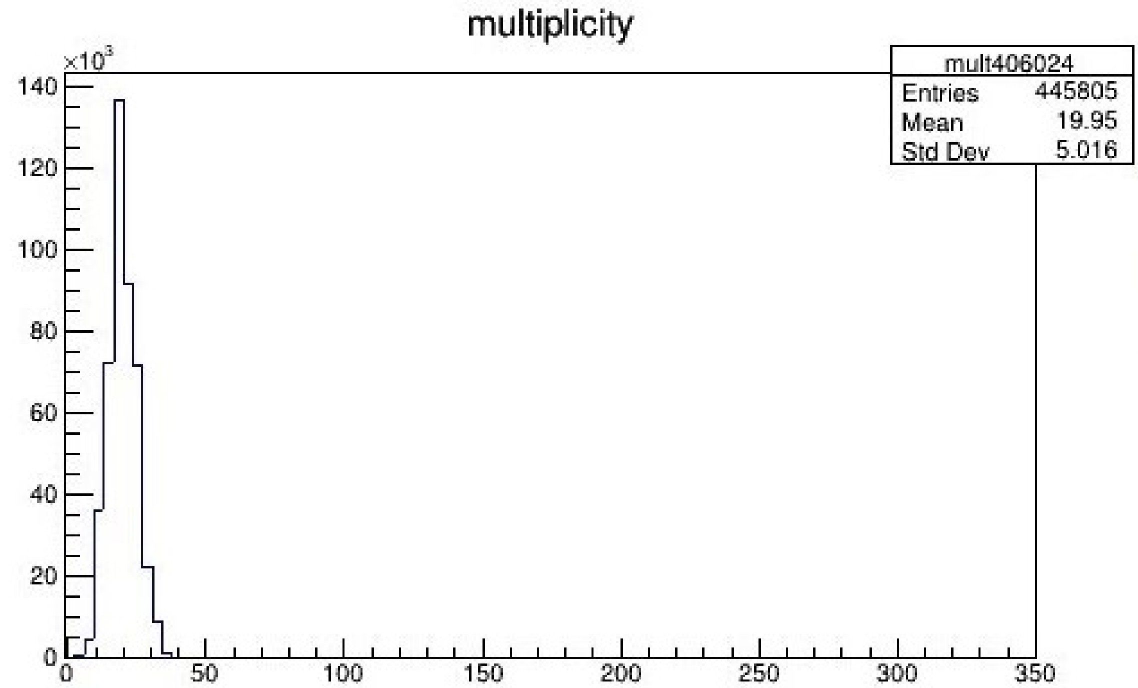

Figure 3. Distribution of multiplicity for proton-proton collisions in the multiplicity class pytree4060
$\langle N_{ch}\rangle = 19.95 \quad \sigma^2_{ch} = 25.160 \quad \omega_{ch} = 1.261 \quad \sigma^2_{ch}/\langle N_{ch}\rangle^2 = 0.063$

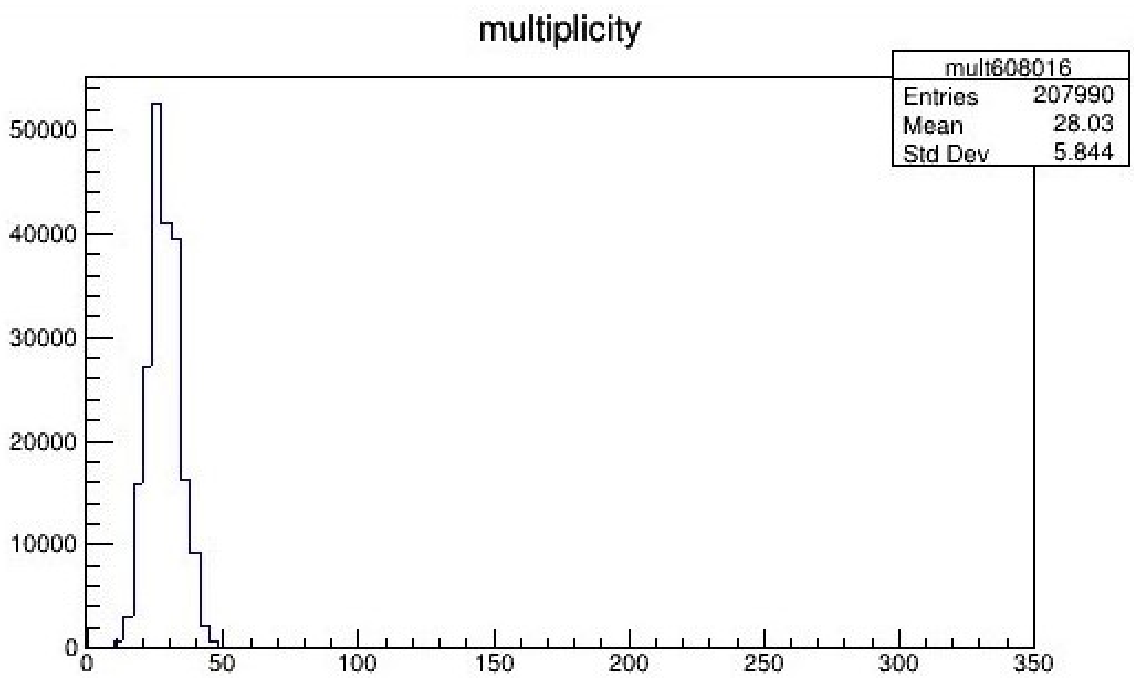

Figure 4. Distribution of multiplicity for proton-proton collisions in the multiplicity class pytree6080
$\langle N_{ch}\rangle = 28.03 \quad \sigma^2_{ch} = 34.152 \quad \omega_{ch} = 1.219 \quad \sigma^2_{ch}/\langle N_{ch}\rangle^2 = 0.043$

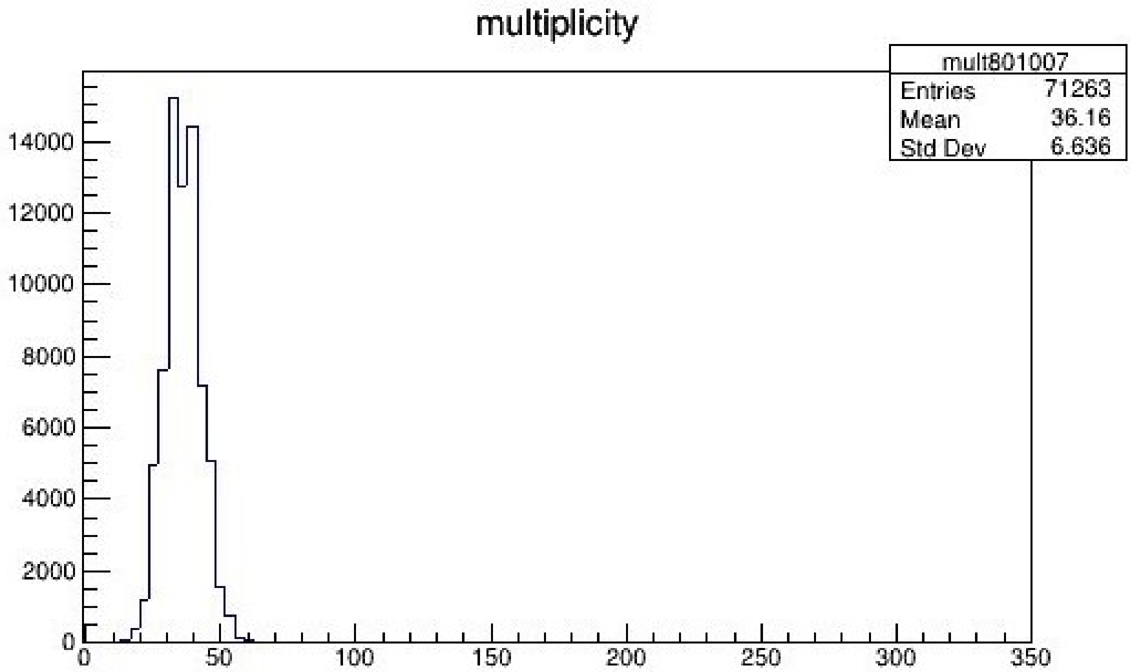

Figure 5. Distribution of multiplicity for proton-proton collisions in the multiplicity class pytree80100
$\langle N_{ch} \rangle = 36.16 \quad \sigma^2_{ch} = 44.036 \quad \omega_{ch} = 1.218 \quad \sigma^2_{ch}/\langle N_{ch} \rangle^2 = 0.034$

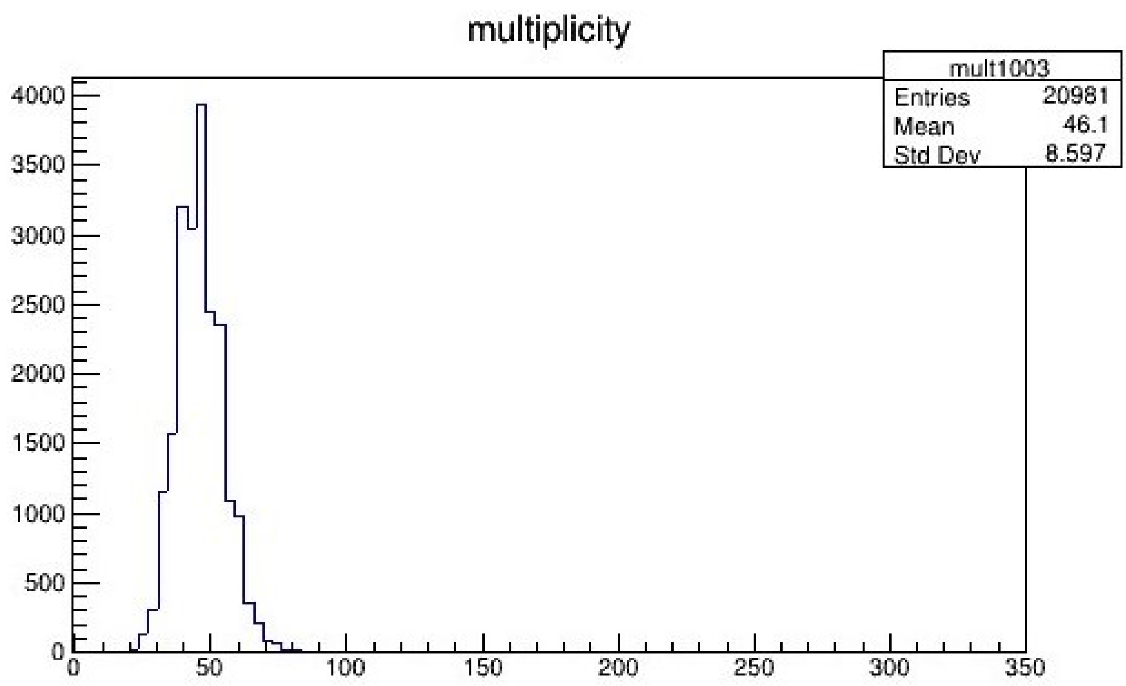

Figure 6. Distribution of multiplicity for proton-proton collisions in the multiplicity class pytree100
$\langle N_{ch} \rangle = 46.1 \quad \sigma^2_{ch} = 73.908 \quad \omega_{ch} = 1.603 \quad \sigma^2_{ch}/\langle N_{ch} \rangle^2 = 0.034$

In the given test region, by applying a counter for the accepted events, we plot the multiplicities observed as shown above. ROOT then proceeds to extract the mean ($< N_{ch} >$) and standard deviation ($< \sigma_{ch} >$) of this distribution for the selected centrality class. Using this data, we compile a table as shown below:

SUMMARY OF DATA					
Multiplicity Class	**Events**	$\langle \mathbf{N_{ch}} \rangle$	$\sigma^2_{\mathbf{ch}}$	$\omega_{\mathbf{ch}}$	$\sigma^2_{\mathbf{ch}}/\langle \mathbf{N_{ch}} \rangle^2$
pytree020	2380640	3.562	7.134	2.003	0.562
pytree2040	860139	11.73	16.419	1.400	0.119
pytree4060	445805	19.95	25.160	1.261	0.063
pytree6080	207990	28.03	34.152	1.219	0.043
pytree80100	71263	36.16	44.036	1.218	0.034
pytree100	20981	46.1	73.908	1.603	0.034

Table I. Table summarizing the data and parameters extracted from the plots for different multiplicity classes

Figure 7 highlights the multiplicity dependence of the mean multiplicity. We can fit a linear curve to the predicted points, and our observation is consistent with the expected result. Note that the large sample size ensures that the deviations from the line of best fit are minimal and the observed points almost lie exactly on the linear fit.

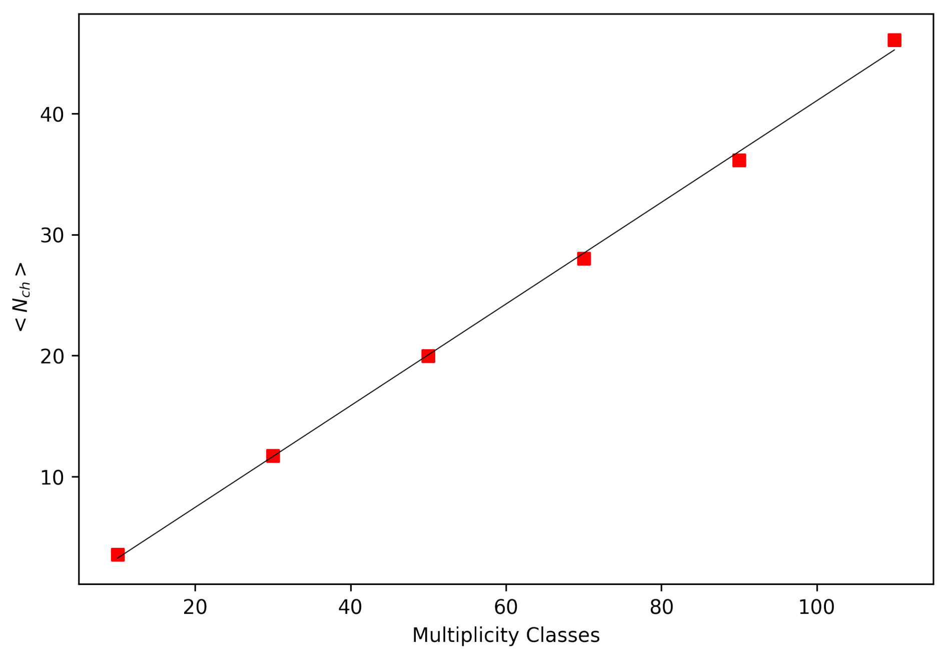

Figure 7. $< N_{ch} >$ versus multiplicity class

The equation of the line of best fit is $y = 0.42x - 0.95$.

Figure 8 highlights the multiplicity dependence of the variance of multiplicity. We can fit a linear curve to the predicted points, and our observation is consistent with the expected result. Note that the large sample size ensures that the deviations from the line of best fit are minimal and the observed points almost lie exactly on the linear fit.

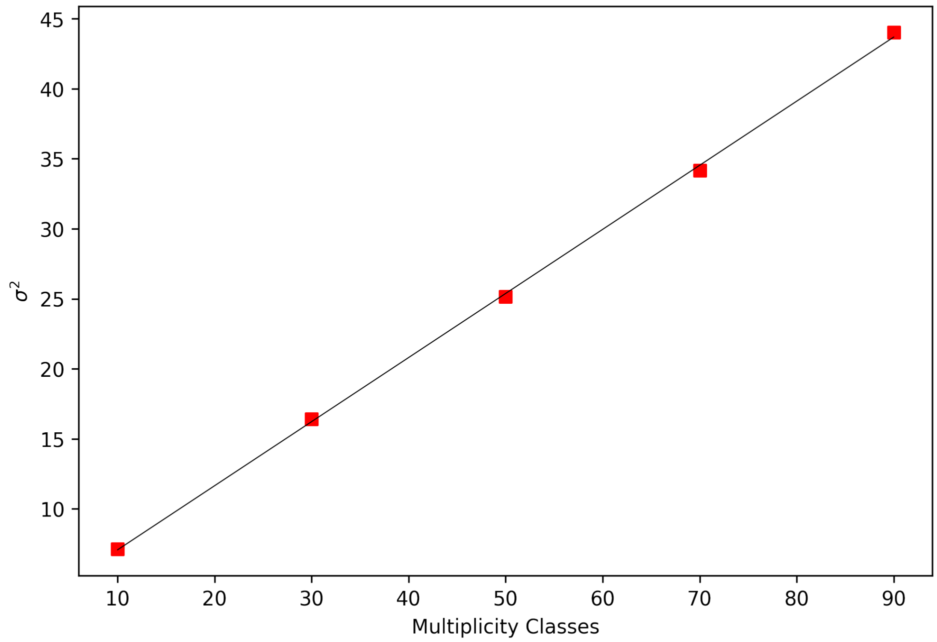

Figure 8. σ^2_{ch} versus multiplicity class
The equation of the best fit line is $y = 0.46x + 2.50$.

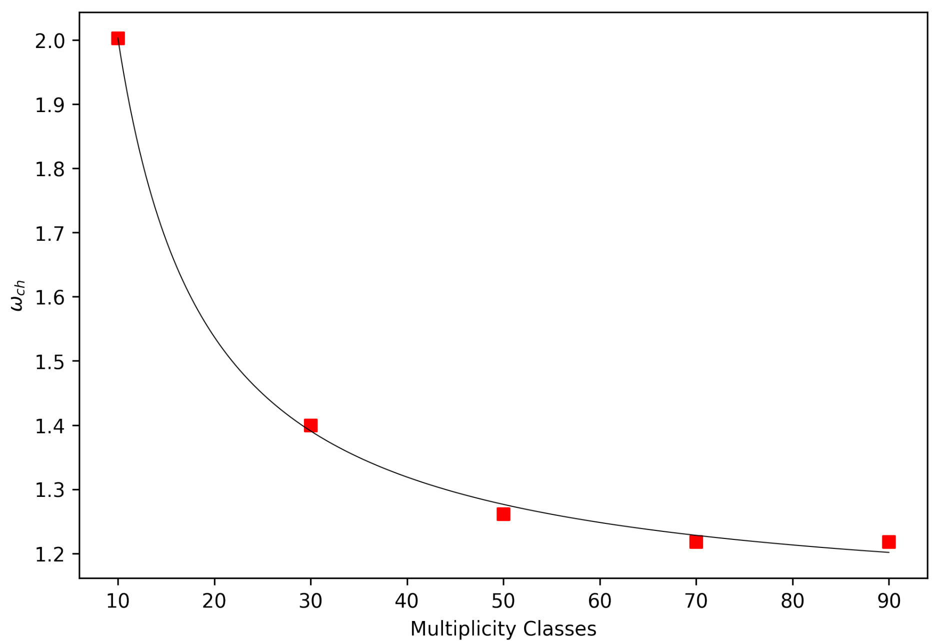

Figure 9. ω_{ch} versus multiplicity class
The solid curve is an exponential fit to the data of the form $y = ae^{b/x} + c$.
The values of the constants in the curve's equation are $a = 4.85$, $b = 1.69$, and $c = -3.74$.

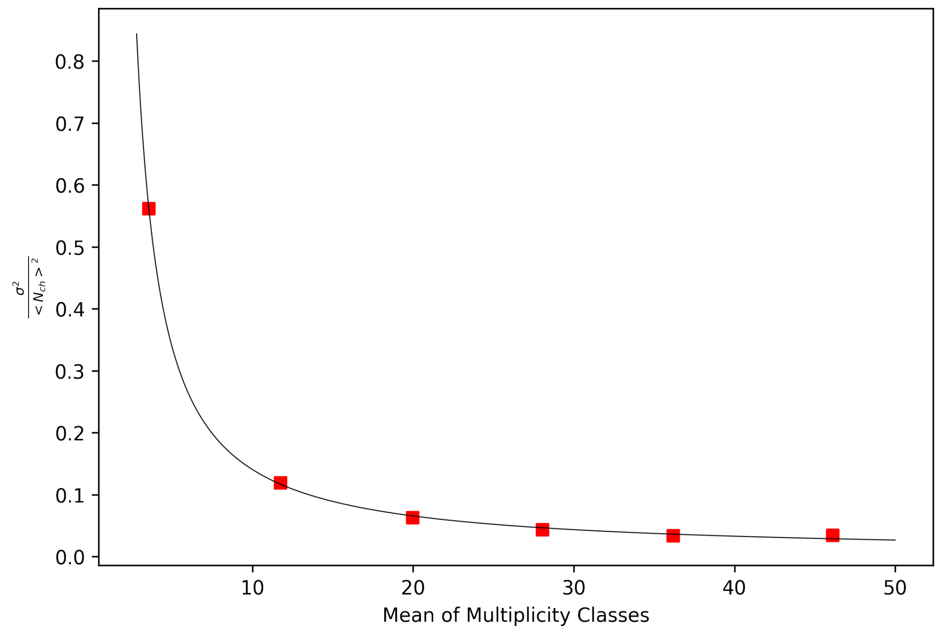

Figure 10. $\frac{\sigma_{ch}^2}{(<N_{ch}>)^2}$ versus mean of multiplicity class.

The solid curve is an exponential fit to the data of the form $y = ae^{b/x} + c$. The scaled variance has been renormalized by the mean, and therefore, the data point of the 100+ multiplicity class, too, lies on the curve. The values of the constants in the curve's equation are $a = 0.31$, $b = 3.67$, and $c = -0.31$.

We now plot the logarithmic graphs of these entities. The trends observed in such plots are more accurate especially for larger datasets such as the one we are analyzing. We also note that the slight deviations from the best fit curves have been amplified due to the logarithmic nature of the graphs.

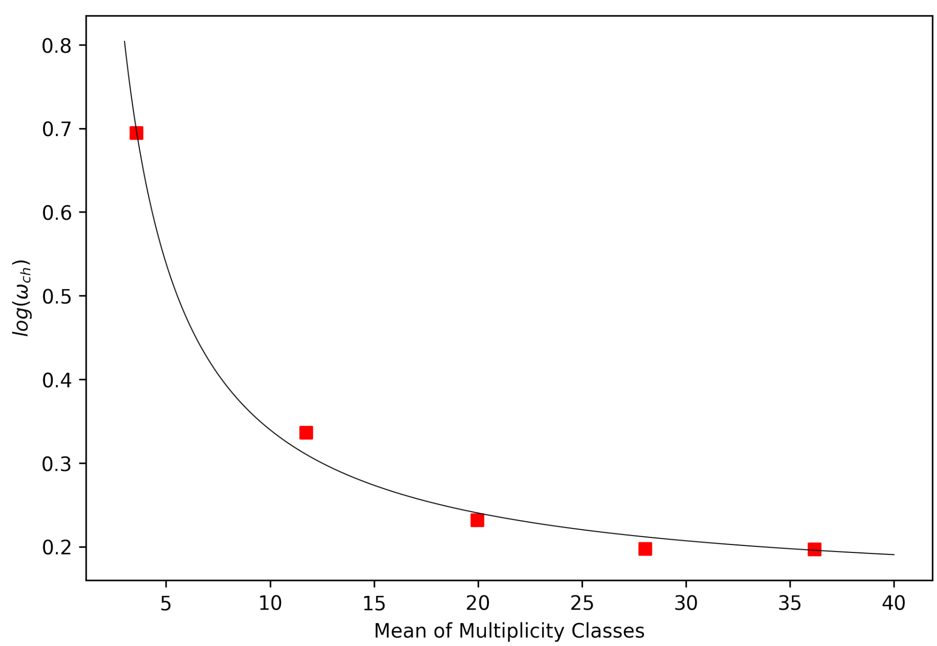

Figure 11. $\log(\omega_{ch})$ versus mean of multiplicity class.

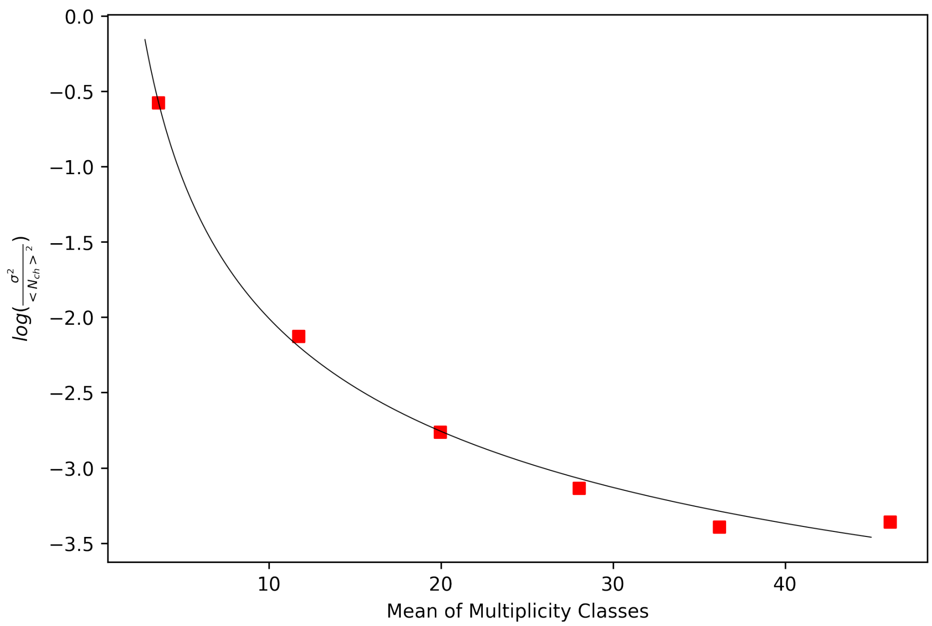

Figure 12. $\log(\frac{\sigma_{ch}^2}{(<N_{ch}>)^2})$ versus mean of multiplicity class.

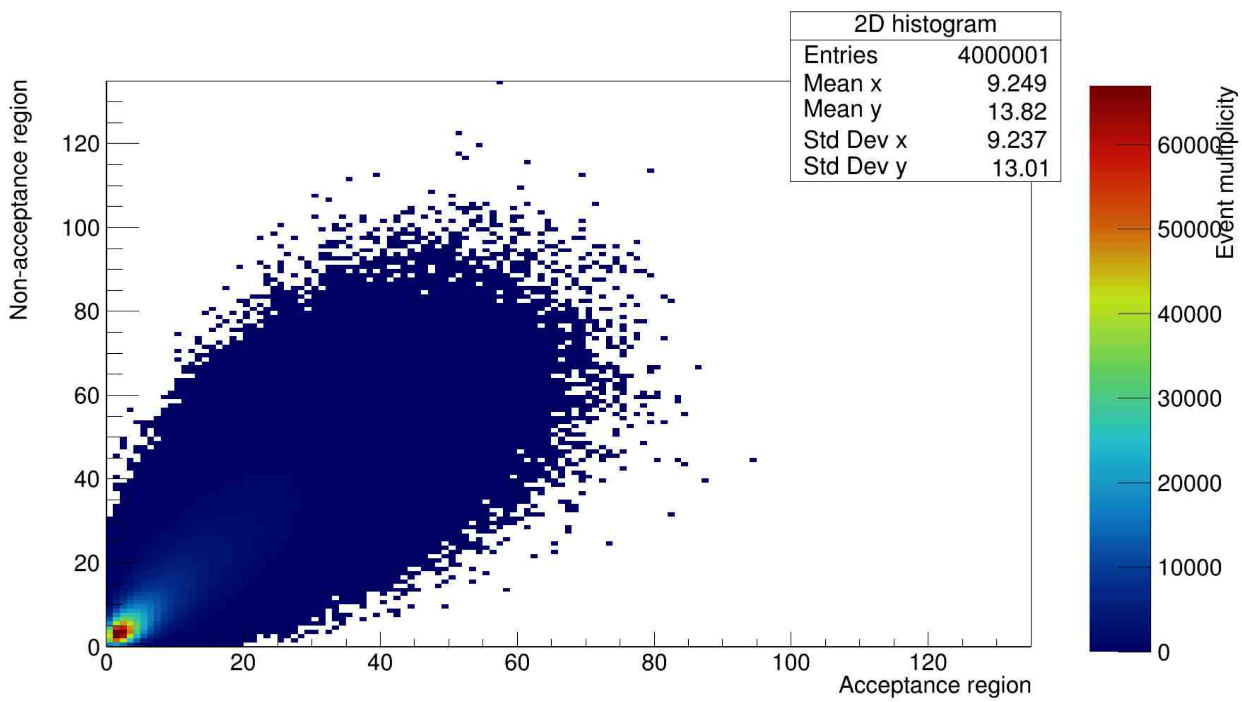

Figure 13. A rather interesting and informative 2D histogram. The x-axis has multiplicity classes for the acceptance region ($\eta < 1.0$), while the y-axis has multiplicity classes for the non-acceptance region ($\eta > 1.5$). The color of the data points represents the "height" on the z-axis, ie, the number of events with said x and y multiplicities.

We expect a correlation coefficient in the range of 0.75-0.9 for an independent analysis on two different regions of observance. In fact, we observe a correlation coefficient of 0.85. This implies there is a strong positive correlation between our analysis in the given region ($\eta < 1.0$) and the same analysis outside the region ($\eta > 1.5$). In other words, any conclusions or trends observed are not specific to the given restricted region of ($\eta < 1.0$) and can be similarly extended to other regions of analysis.

III. SUMMARY

The fluctuations occurring in the multiplicities of emitted particles in the proton-proton collisions have several underlying causes. It has been shown that useful data regarding the nature of statistical fluctuations can be obtained by analyzing the distribution of $\langle \mathbf{N_{ch}} \rangle$, $\sigma^{\mathbf{2}}_{\mathbf{ch}}$ and $\omega_{\mathbf{ch}}$. Initially, we are provided with the graphs of the count/frequency of the multiplicities plotted against the multiplicities for each of the six multiplicity classes. With the help of these graphs, we extract the mean and standard deviation of the multiplicity fluctuations for every multiplicity class with the help of ROOT. With this data, we now plot $\langle \mathbf{N_{ch}} \rangle$ (mean), $\sigma^{\mathbf{2}}_{\mathbf{ch}}$ (variance), $\omega_{\mathbf{ch}}$ (scaled variance) and $\sigma^{\mathbf{2}}_{\mathbf{ch}}/\langle \mathbf{N_{ch}} \rangle^{\mathbf{2}}$ against the multiplicity classes. On studying these plots carefully, we arrive at the following conclusions:-

(i) We observe a monotonically decreasing trend for the scaled variance as we move from peripheral to central collisions except for the 100+ multiplicity class in which the scaled variance jumps significantly owing to the sharp increase in standard deviation of the 100+ class compared to the 80-100 class.

(ii) We also observe a monotonically decreasing trend for the plot of $\sigma^{\mathbf{2}}_{\mathbf{ch}}/\langle \mathbf{N_{ch}} \rangle^{\mathbf{2}}$ as we move from peripheral to central collisions with the values for the 80-100 and 100+ classes being almost equal.

(iii) We have restricted our analysis to proton-proton collisions in the pseudorapidity range $|\eta| < 1.0$ and transverse momentum $p_T > 0.05 GeV/c$ but with further analysis, it can be shown that the scaled variance of the multiplicity decreases with the reduction of the η acceptance of the detector as well as with the decrease of the p_T range.

The observations for $N_c h$ and $\sigma^2_c h$ in this paper are similar to the observations from the experiment with the ALICE detector. The behaviours (trend) of proton-proton collisions are similar to heavy-ion collisions as analysed in ALICE. More investigation is required before any conclusion can be made. It will be interesting to see similar analyses and investigation of real data for different sets of energies.

The statistics are too small to draw concrete conclusions, but we observe similar trends as seen in Pb-Pb collisions. 2 million collisions are too little to make rigorous predictions, but the trends follow similar patterns as analysed in heavy-ion collisions.